

First photometric study of the eclipsing binary PS Persei

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Abstract The CCD photometric observations of the eclipsing binary PS Persei (PS Per) were obtained on two consecutive days in 2009. The 2003 version Wilson-Devinney code was used to analyze the first complete light curves in V and R bands. It is found that PS Per is a short-period Algol-type binary with the less massive component accurately filling its inner critical Roche lobe. The mass ratio of $q = 0.518$ and the orbital inclination of $i = 89.^\circ 86$ are obtained. On the other hand, based on all available times of primary light minimum including two new ones, the orbital period has been improved.

Key words: stars: binaries: close — stars: binaries: eclipsing — stars: individual: PS Per

1 INTRODUCTION

PS Per ($\alpha_{2000.0} = 02^h 39^m 33.^s 3$ and $\delta_{2000.0} = +45^\circ 38' 05.'' 5$) was designated by Kukarkin et al. (1968). But photographic and visual times of light minimum have been obtained since 1926. Later, Photoelectric and CCD times of light minimum were published by Šafář & Zejda (2000a), Šafář & Zejda (2000b), Zejda (2002), Agerer & Hübscher (2003), Zejda (2004), Diethelm (2005), Hübscher et al. (2006), Zejda et al. (2006), Brát et al. (2009), and Diethelm (2010). But, no complete light curve of the binary system have been made so far for photometric analysis.

In this paper, the first complete light curves in V and R bands were presented. And the absolute physical parameters as well as orbital period were determined.

2 OBSERVATIONS

New CCD photometric observations of PS Per in V and R bands were carried out on 2009 November 13 and 14 using the 85-cm telescope at the Xinglong Station of National Astronomical Observatory of China (NAOC), equipped with a primary-focus multicolor CCD photometer. The telescope provides a field of view of about $16.'' 5 \times 16.'' 5$ at a scale of $0.'' 96$ per pixel and a limit magnitude of about 17 mag in V band.

The typical exposure times in V and R bands were 90s and 60s respectively. The coordinates of the variable, comparison, and check stars are listed in Table 1. The data reduction was performed by using the aperture photometry package IRAF¹ (bias subtraction, flat-field division). Extinction corrections were ignored as the comparison star is very close to the variable. In total, 445 CCD images in the V band and 446 images in the R band were obtained. Several new times of light minimum (see Table 2) are derived from the new observation by using a parabolic fitting method.

The first complete light curves in V and R bands are obtained, and displayed in the top panel of Figure 1. The new orbital period revised in the next section was used to calculate the phase.

¹ IRAF is developed by the National Optical Astronomy Observatories, which are operated by the Association of Universities for Research in Astronomy, Inc., under contract to the National Science Foundation.

Table 1 Coordinates of PS Per and its Comparison and Check Stars.

Stars	α_{2000}	δ_{2000}
PS Per	$02^h 39^m 33.3^s$	$45^\circ 38' 05.5''$
Comparison	$02^h 39^m 24.1^s$	$45^\circ 42' 22.1''$
Check	$02^h 39^m 22.2^s$	$45^\circ 43' 34.0''$

Table 2 New CCD Times of Light Minimum for PS Per.

No.	J.D. (Hel.) (days)	Error (days)	Min.	Filter
1	2455149.2742	± 0.0004	I	<i>V</i>
	2455149.2752	± 0.0005	I	<i>R</i>
2	2455149.9768	± 0.0003	I	<i>V</i>
	2455149.9768	± 0.0004	I	<i>R</i>
3	2455150.3267	± 0.0004	II	<i>V</i>
	2455150.3265	± 0.0004	II	<i>R</i>

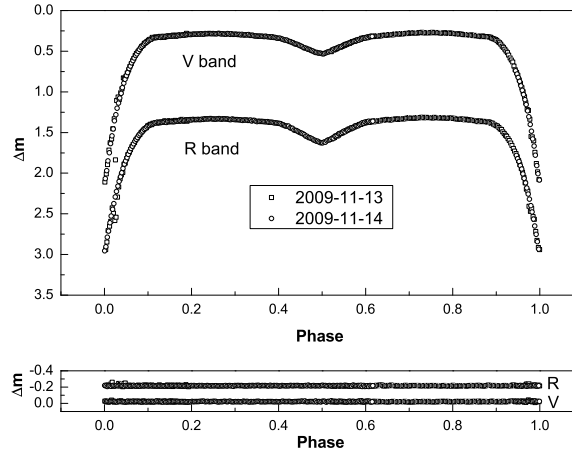


Fig. 1 Top panel: the light curves of PS Per in the *V* and *R* bands obtained on 2009 November 13 and 14. The points in *R* band has been shifted down by 1.0 mag. Bottom panel: the differential light curves of the comparison star relative to the check star. The points in *R* band has been shifted up by 0.2 mag.

3 ORBITAL PERIOD STUDY

All available times of primary light minimum seen in literature were collected and listed in Table 3, which also includes the data in the database of eclipsing binaries of Kreiner (2004). For my two-band light minima, a mean time of light minimum is given. The $O - C$ values of all minimum times were computed with the ephemeris given by Kreiner et al. (2001):

$$\text{Min } I = 2424527.2165 + 0^d.70217968 \times E, \quad (1)$$

and listed in the fifth column of Table 3. The corresponding $O - C$ diagram, Figure 2, shows that the data are distributed around a straight line. So, a linear ephemeris was used to fit the $O - C$ values. The photographic and visual data show large deviation from the straight line for their low quality. In the fitting process, a weight of 10 is used for photoelectric and CCD data, and 1 for photographic and visual data. The CCD times, 2451841.3121 and 2452213.4662, have the weight of 1 for their large errors. A least-squares fit to the data gave the following ephemeris:

$$\text{Min } I = 2424527.2163 + 0^d.70217977 \times E, \quad (2)$$

The new ephemeris is plotted in Figure 2 with a solid line. The residuals with respect to Equation (2) are listed in the sixth column of Table 3.

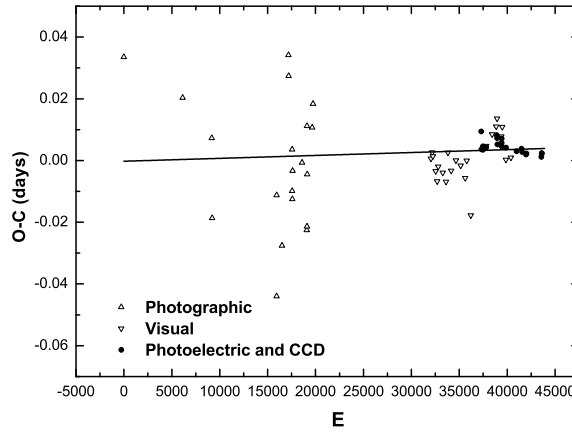


Fig. 2 $O - C$ diagrams. The solid line is calculated with the new ephemeris in Equation (2).

4 PHOTOMETRIC SOLUTIONS WITH THE W-D METHOD

The light curves were analyzed using the 2003 version of the Wilson-Devinney code (Wilson & Devinney 1971; Wilson 1979, 1990). Since the spectral type of PS Per is F5, an effective temperature of $T_1 = 6750\text{K}$ is assumed for the primary component. Assuming the photospheric surface of the binary star is convective, gravity-darkening coefficients ($g_1 = g_2 = 0.320$) and bolometric albedo ($A_1 = A_2 = 0.5$) were used. According to the tables of van Hamme (1993), the limb-darkening coefficients 0.506 for V band ($x_{1V} = 0.506$) and 0.414 for R band ($x_{1R} = 0.414$) were adopted.

Since no mass ratio has been published in literature, a q -search method was used to determine the mass ratio. Solutions were carried out for a series of values of the mass ratio $q = M_2/M_1$ ($q = 0.3, 0.4, 0.5, 0.6, 0.7, 0.8, 0.9, 1.0$). Considering the light curves of EB type, mode 2 (detached mode) is assumed. The behavior of the sum of the residuals squared, Σ , as a function of mass ratio q is plotted in Figure 3, showing that Σ reaches the minimum value near $q = 0.5$. Therefore, the mass ratio was taken as an adjustable parameter and given the initial value of $q = 0.5$. After some differential corrections, The solution converged to mode 5 (semi-detached) and gave the final mass ratio of $q = 0.518$. The derived physical parameters are listed in Table 4. The theoretical light curves computed with the parameters are plotted in Figure 4 as a solid line.

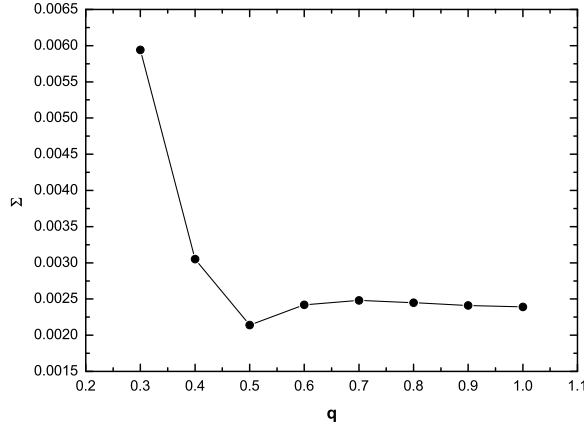


Fig. 3 Relation between Σ (the sum of the residuals squared) and q for PS Per.

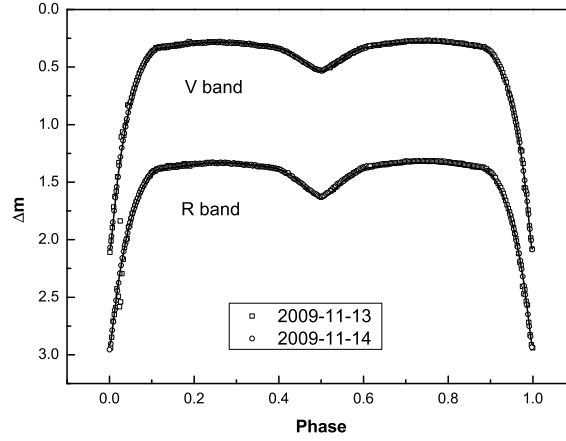


Fig. 4 Same as the top panel of Figure 1. But the solid curves represent the theoretical light curves computed with the parameters in Table 4.

5 DISCUSSION AND CONCLUSIONS

In this paper, my photometric solution reveals that PS Per is a semi-detached system. The Roche-geometry configuration that the less massive and cool secondary component fills its inner Roche lobe permits a dynamical mass transfer from the secondary to the more massive primary star, suggesting a continuous period increase just as in AI Cru (Zhao et al. 2010) and DD Mon (Qian et al. 2009). The orbital period of PS Per, however, does not show continuous increase in this paper. This may be due to the low quality of photographic and visual times, and the short span of photoelectric and CCD times. In

order to confirm the mass transfer from the secondary to the primary star, long-term orbital timing data are required.

According to the derived physical parameters listed in Table 4 and the Harmanec's (1988) relation for masses and radii as functions of spectral type, the following orbital parameters can be derived: $M_1 = 1.31 M_\odot$, $R_1 = 1.39 R_\odot$, $L_1 = 3.62 L_\odot$, $M_2 = 0.68 M_\odot$, $R_2 = 1.35 R_\odot$, $L_2 = 0.89 L_\odot$, and $a = 4.19 R_\odot$. In order to further verify the parameters, Spectroscopic observations of the radial velocity curves of both components are needed.

As showed in Figure 1, the second maxima of the light curves are a little higher than the primary maxima. The weak O'Connell effect maybe arises from a hot spot on the primary component as a result of the impact of the gaseous stream from the cooler, less massive secondary component. Such hot spot is often seen in other semi-detached binary systems, such as CL Aur (Lee et al. 2010) and KQ Gem (Zhang 2010). Considering the late spectral type and fast rotation of the secondary star, The asymmetry of the light curves can be also attributed to a cool spot on the secondary star caused by magnetic activity. It is a reasonable trial that the magnetic activity makes the light curves show more variability than the impact of the gaseous stream does. So, in order to tell the two mechanisms of magnetic activity and impact of the gaseous stream, the investigation on long-term behaviour of the light curves is also needed.

Acknowledgements I thank an anonymous referee for some useful suggestions. This work is supported by Natural Science Foundation of Shanxi Normal University (No. ZR09002).

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Table 3 Times of primary light Minimum for PS Per.

JD (Hel.)	Method	Error	E	$O - C$	Residuals	Ref.
2424527.250	p		0	0.03350	0.03374	MVS 2
2428834.407	p		6134	0.02034	0.02000	MVS 2
2430972.531	p		9179	0.00722	0.00660	MVS 2
2430991.464	p		9206	-0.01863	-0.01925	MVS 2
2435718.545	p		15938	-0.01124	-0.01249	MVS 2
2435725.534	p		15948	-0.04404	-0.04529	MVS 2
2436114.558	p		16502	-0.02758	-0.02888	MVS 2
2436596.315	p		17188	0.03416	0.03278	MVS 2
2436603.330	p		17198	0.02736	0.02598	MVS 2
2436850.460	p		17550	-0.00988	-0.01128	MVS 2
2436852.580	p		17553	0.00358	0.00217	MVS 2
2436876.438	p		17587	-0.01253	-0.01393	MVS 2
2436895.406	p		17614	-0.00338	-0.00479	MVS 2
2437588.460	p		18601	-0.00073	-0.00223	MVS 2
2437939.528	p		19101	-0.02257	-0.02412	MVS 2
2437944.477	p		19108	0.01117	0.00961	MVS 2
2437946.551	p		19111	-0.02136	-0.02291	MVS 2
2437970.442	p		19145	-0.00447	-0.00602	MVS 2
2438321.547	p		19645	0.01069	0.00908	MVS 2
2438385.453	p		19736	0.01834	0.01672	MVS 2
2447028.565	v		32045	0.00065	-0.00211	BBSAG 85
2447118.446	v		32173	0.00266	-0.00011	BBSAG 86
2447170.406	v		32247	0.00136	-0.00142	BBSAG 87
2447384.566	v		32552	-0.00344	-0.00625	BBSAG 89
2447491.294	v		32704	-0.00675	-0.00957	BBSAG 90
2447566.432	v		32811	-0.00198	-0.00481	BBSAG 91
2447894.348	v		33278	-0.00389	-0.00677	BBSAG 94
2448136.597	v		33623	-0.00688	-0.00979	BBSAG 96
2448283.362	v	.004	33832	0.00257	-0.00036	BBSAG 97
2448509.458	v	.005	34154	-0.00329	-0.00625	BBSAG 99
2448867.573	v	.003	34664	0.00007	-0.00294	BBSAG 102
2449202.511	v	.004	35141	-0.00163	-0.00468	BBSAG 104
2449546.575	v	.006	35631	-0.00568	-0.00878	BBSAG 107
2449653.312	v	.003	35783	0.00001	-0.00310	BBSAG 108
2449945.401	v	.005	36199	-0.01774	-0.02089	BBSAG 110
2450713.6127	cc	.0014	37293	0.00939	0.00612	Šafář & Zejda (2000a)
2450721.3309	cc	.0008	37304	0.00362	0.00035	BBSAG 116
2450839.2981	cc	.0021	37472	0.00463	0.00135	Šafář & Zejda (2000b)
2450841.4035	cc	.0021	37475	0.00349	0.00021	Šafář & Zejda (2000b)
2451077.3366	cc	.0006	37811	0.00422	0.00091	BBSAG 119
2451088.572	v	.003	37827	0.00474	0.00142	BBSAG 119
2451515.501	v	.008	38435	0.00850	0.00513	BBSAG 121
2451810.419	v	.005	38855	0.01103	0.00762	BBSAG 123
2451841.3121	cc	.0058	38899	0.00823	0.00481	Zejda (2002)
2451876.4201	cc	.0017	38949	0.00724	0.00382	Zejda (2002)
2451878.533	v	.008	38952	0.01360	0.01018	BBSAG 124
2451899.5900	cc	.0003	38982	0.00521	0.00179	Agerer & Hübscher (2002)
2452190.295	v	.003	39396	0.00783	0.00437	BBSAG 126
2452204.3365	cc	.0010	39416	0.00573	0.00227	BBSAG 126
2452213.4637	cc	.0005	39429	0.00460	0.00113	BBSAG 127
2452213.4662	cc	.0070	39429	0.00710	0.00363	Zejda (2004)
2452260.516	v	.004	39496	0.01086	0.00739	BBSAG 127
2452524.525	v	.007	39872	0.00030	-0.00320	Diethelm (2003)
2452531.5507	pe	.0002	39882	0.00420	0.00069	Agerer & Hübscher (2003)
2452885.446	v	.002	40386	0.00094	-0.00261	Diethelm (2004)
2453302.5428	cc	.0010	40980	0.00301	-0.00059	Diethelm (2005)
2453656.4422	cc	.0003	41484	0.00385	0.00019	Zejda et al. (2006)
2453705.5937	pe	.0008	41554	0.00278	-0.00088	Hübscher et al. (2006)
2453988.5713	cc	.0001	41957	0.00197	-0.00172	Brát et al. (2009)
2454019.4675	cc	.0001	42001	0.00226	-0.00144	Brát et al. (2009)
2455114.8667	cc	.0006	43561	0.00116	-0.00268	Diethelm (2010)
2455149.2747	cc	.0003	43610	0.00236	-0.00149	this paper
2455149.9768	cc	.0003	43611	0.00228	-0.00157	this paper

Table 4 Photometric Solutions for PS Per.

Parameters	Photometric elements	Errors
$g_1 = g_2$	0.32	assumed
$A_1 = A_2$	0.5	assumed
x_{1bol}	0.480	assumed
x_{2bol}	0.536	assumed
x_{1V}	0.506	assumed
x_{1R}	0.414	assumed
x_{2V}	0.726	assumed
x_{2R}	0.600	assumed
T_1	6750K	assumed
$q(M_2/M_1)$	0.518	0.003
$\Omega_{in} = \Omega_2$	2.8944	—
Ω_{out}	2.5907	—
T_2	4822K	7K
i	$89.^\circ 86$	$0.^\circ 35$
Ω_2	3.590	0.008
$r_1(pole)$	0.3229	0.0008
$r_1(side)$	0.3317	0.0009
$r_1(back)$	0.3402	0.0010
$r_2(pole)$	0.3025	0.0004
$r_2(side)$	0.3159	0.0005
$r_2(back)$	0.3483	0.0005
$\Sigma(O - C)^2$	0.0022	